GROUTING AS A MEAN FOR REPAIRING EARTH CONSTRUCTIONS

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Abstract
A good condition of the structural elements of an earth construction is essential for a good global structural behaviour. Therefore, the absence of major cracks is essential. Repairing cracks by using traditional techniques, involving the partial or the total reconstructions of the structural elements, constitutes a very intrusive solution that must, necessarily, be avoided in the case of historical earth constructions. Grouting constitutes an alternative and more practical solution for solving this problem. However, the design of the grouts for earth constructions demands the implementation of a methodical process that accounts both for the structural and durability demands of the construction. Previous works showed that the injection of mud grouts is a reliable and feasible solution. However, the knowledge developed is still very limited, hindering the further development of a methodology for designing mud grouts for earth constructions. Therefore, in this paper an initial methodology proposal for the design of mud grouts is presented and discussed. This results from an ongoing research that aims at the development of suitable grouts for earth constructions.

1. INTRODUCTION

The recently increasing interest in earth constructions, as well as the will in re-discovering this building typology, have increased the research being carried out in this field. However, the scientific knowledge about earth construction is still limited. One of the areas, where this limitation is strongly noticed, is in the knowledge about the structural behaviour of this kind of constructions. This problem is increased by the fact that most of the times this is a weak point of the earth constructions, especially if they are built in seismic areas. It is known that, in general, earthen materials present low mechanical properties, which in part explains their deficient structural behaviour. The deficient connections between earthen structural elements are another factor contributing for their poor structural behaviour. In the last years, research efforts were carried out aiming to develop solutions for improving the structural behaviour of earth constructions. Most of these solutions are to be applied to new earth constructions, involving changes in the building processes and inclusion of other materials further than simply earth. Progresses are also made towards the development of solutions for improving the structural behaviour of existent earth constructions. Nevertheless, a good condition of the structural elements of an earth construction is essential for a good global structural behaviour. The absence of major cracks is essential for granting this good condition. Cracks in earth constructions can have several sources, such as: (i) earthen materials shrinkage; (ii) structural defects; (iii) thermal movements; (iv) foundation settlements; (v) plant growth; and (vi) earthquakes. The repair of earth constructions is carried out most of the times by rebuilding the damaged elements or by restoring the missing material. Rebuilding the damaged elements or part of them, is a very intrusive solution, since it implies the substitution of the original materials. In historical constructions, repair is always preferable to reconstruction (ICOMOS, 2003; p. 8), even if earthen materials are used.

Currently, a solution is being developed for repairing earth constructions based on grout injection. However, this is an irreversible solution. Therefore, interventions involving grout injection and historical earth constructions distress of special care. Another benefit of repairing cracks is the prevention of further decay on earthen constructions. In general, cracks constitute a way for water infiltration, which can result in its enlargement and weakening of the surrounding earthen material. Grouting can also constitute a feasible solution for filling voids in the earthen materials, and in this way achieve an improved mechanical behaviour.

The selection of the materials, used for repairing earth constructions by grout injection, has to be carefully evaluated, keeping in mind the risk of compromising their integrity. Using modern materials, such as cement, have many drawbacks as it was observed in historical masonry constructions during many years. One example of the drawbacks of the use of cement in historical masonry is the high strength and stiffness of the repairing materials being incompatible with the ones of the original materials. Other examples are the incompatible microstructure, the salt content and etc. Therefore, the use of cement in the composition of grouts for historical masonry is limited to a minimum amount needed to obtain the grout hardening within an acceptable time span. This led to the development of binary and ternary grouts, which are composed mainly of lime and pozzolan, like most of the historical mortars.

Additionally, a low percentage of cement is added, regarding to the reason previously mentioned. These grouts allowed achieving durable and reliable grouting solutions for historical masonry, which could not be achieved with the traditional cement grouts, neither with organic grouts. Using binary or ternary grouts, for repairing earth constructions, can have analogous drawbacks to the ones of the injection of cement grouts in history masonry. Binary or ternary grouts are, in general, greatly stronger and stiffer than earthen materials are. Therefore, there is a mechanical incompatibility between both materials. The way in which the two materials harden is different as well. The hardening of binary or ternary grouts occurs due to hydration and carbonation reactions of its components (lime, pozzolan and cement) while the hardening of earthen materials occurs due to drying and it is provided by the clay fraction. Between many things, this result in differences on the microstructure of both materials, that may not be compatible. Using cement in the composition of the grout is also a problem for earth constructions, since the content of sulphates in earthen materials is typically high. Therefore, there exists the risk of the formation of expansive products, which can cause damage to the construction. An obvious solution to counter these problems consists in incorporating earth in the grouts, normally called of mud grouts. However other problems arise, as it will be discussed later.

Therefore, an initial methodology for the design of mud grouts will be presented and discussed in this paper, having by base the methodology extensively followed for the design of grouts for historic masonry.

2. DESIGN OF GROUTS FOR MASONRY

A grout can be defined as a "*fluid mortar employed for the filling, homogenization, imperviousness, consolidation and/or upgrading of the mechanical properties of systems presenting pores, voids, cracks, loss of cohesion or of cohesionless systems*" (Toumbakari, 2002, p. 6). In general, grouts are composed by fillers and binders. Two major groups can be distinguished among the binder materials: the organic and the inorganic (or mineral) binders. The main materials of organic binders are polymeric systems, which can be applied in pure form, pigmented or filled with filling materials. The inorganic binders include air-hardening binders, such as hydrated lime, and hydraulic binders, such as hydraulic lime, Portland cement and all kind of modern cements, lime-pozzolan mixtures and any combination of the previous (Toumbakari, 2002, p. 7).

Grouting has been successively applied in the consolidation of historical masonry constructions during the last years, since it allows economical and reliable solutions. Especially, when applied to three-leave masonry walls. In this typology of masonry, grouting aims to reduce the weakness of the internal core by filling the existing voids and cracks with the hardened grout, and to improve the bond with the external leaves. This is promoted by the high open porosity of the infill material of the internal core, which allows the grout to flow through the intercommunicated voids and reach every empty space in the material. With this technique it is also possible to repair deep and thin cracks lying in the external leaves of three-leaf masonry or in single leaf masonry.

The non reversibility of the grouting technique constitutes its major drawback, since a wrong decision on the materials composing the grout can induce durability and compatibility problems with the injected system. Thereby, nowadays the trend is the injection of binary (mixes of cement and hydrated lime, natural or artificial pozzolans, silica fume, etc.) or ternary (cement, hydrated lime and natural or artificial pozzolans) grouts with low cement content (Vintzileou and Miltiadou-Fenzas, 2008, p.2265). During many years the aim of grouting historical masonry was exclusively to improve the mechanical properties of the injected masonry, rather than having in mind durability and compatibility concerns. After detecting some problems, these concerns became priority, leading to the development of fundamental studies on grout injection of historical masonry. In fact, these studies have shown that the grout compressive strength is not a fundamental parameter for the grout design, encouraging the experimentation of binders others than cement (Toumbakari, 2002, p.25), which led to the development of the binary and ternary grouts.

Furthermore, this kind of grouts, due to its low content in cement and due to the incorporation of materials similar to the original materials of the masonry, allows avoiding compatibility problems, leading to solutions with enhanced durability (Vintzileou and Miltiadou-Fenzas, 2008, p.2266). In a rational grout design methodology for a specific intervention, the requirements for the grout materials shall be defined in the first place. This approach should consider the structure, rather than the material, as the starting point. Therefore, the grout design requirements can be defined in two main categories (Toumbakari, 2002, p.25-26): requirements regarding the mechanical behaviour and the requirements regarding the durability of the injected structure. The improvement of the mechanical behaviour of a structure requires the design of a grout with good injectability and bonding properties, in order to allow the injection of small cracks and voids, and to assure continuity to the masonry. The desired mechanical properties of the grout depend on the structural level of damage and on the structural improvement requirements. It also depends on the time span in which the required mechanical properties must be achieved, since the strength development rate is a controlling factor. For slow hydration or carbonation hardening binders, it is impossible to achieve acceptable levels of strength within a reasonably short time dictated by structural necessities. Table 1 shows a brief description of the grout design requirements concerning the mechanical behaviour of the injected structure. On the other hand, durability requires the development of a microstructure as close as possible to the microstructure of the existing materials. This can be achieved partly with the use of raw materials similar to the existing ones. However, the expected mechanical properties may be insufficient. Thus, a compromise is possible within the use of a limited Portland cement content (Toumbakari, 2002, p.26). The bonding is also a key factor for the durability requirements, since it limits the intrusion of detrimental agents and the subsequent undesirable chemical reactions. A brief description of the durability requirements is presented in Table 2.

Table 1 - Requirements of grouts related to the mechanical behaviour of the injected structure (Credits: Toumbakari, 2002, p.26)

Requirement	Description
Injectability	- low yield value and viscosity - penetrability: in voids with diameter smaller than 0.3 mm - stability: no substantial density gradients along the height of the - low bleeding: lower than 5% after 120 min rest
Bonding with existing materials	- relatively low shrinkage (although autogeneous shrinkage is unavoidable) - minimal heat of hydration - setting and hardening in dry as well as in wet environment
Sufficient mechanical properties within a defined span	- development of the required mechanical properties in 90 days - compressive and flexural strength dictated from the structural analysis

Table 2 - Requirements of grouts related to the durability of the injected structure (Credits: Toumbakari, 2002, p. 26)

Requirement	Description
Compatible microstructure	- compatible porosity and pore size distribution: they depend on the porosity of the existing materials as well as on the required strength of the new materials - type of the hydration products: similar (though not necessarily identical) to the existing
Bonding with the existing materials	- limitation of diffusion of SO_2, chlorides, etc. - resistance against deterioration due to environmental factors
Properties of the raw materials	- minimal content in gypsum and soluble salts (especially in releasable alkali)

3. DESIGN OF GROUTS FOR EARTH CONSTRUCTIONS

3.1 Grouting as a repair solution for earth constructions

As previously referred to, repairing structural cracks is essential for re-establishing the structural integrity of an earth construction. However in rehabilitation interventions on earth constructions, cracks are not often truly repaired. Most of the times, they are “cosmetically” hidden by covering them with a plaster or by filling them with coarse material (pieces of bricks and stones) and huge quantities of mortar. These procedures do not grant an acceptable continuity to the earth construction, and usually cause more problems than they solve (Keefe, 2005, p. 140). The good practice techniques, for structural crack repair in earth constructions walls, require the removal of parts of the original walls, in order to create a key pattern around the crack, and therefore a mechanical connection between both sides. This is carried out by cutting horizontal chases on the wall with a determined spacing, which may destabilize the construction if cut too deeply. The removed material is then replaced by new material, such as mud bricks and earth mortar, which must be well bonded with the original wall material (Keefe, 2005, p.170-174). However, these techniques can be very disturbing and intrusive, which makes the grout injection a more practical and less intrusive solution. Grouting can also be used to fill voids and gaps in the earth construction caused by biological activity, such as the penetration of plant roots or tunnels excavated by animals. Moreover, it can also be used to complement other strengthening/repairing techniques, such as the application of ties.

3.2 Developments made in the design of mud grouts

Some attempts and studies about injecting earth constructions were already carried out by other researchers. The grouts studied or proposed had the incorporation of earth on its composition in common. Besides earth, the blends also incorporated stabilizers, such as bentonite, hydrated lime, hydraulic lime, fly ash, “mercula” clay, Portland cement and gypsum. The results obtained globally showed that grouting earth constructions is a promising and feasible technique. Although, great problems and limitations were noticed, such as the high shrinkage, lack of fluidity and deficient penetration capacity of the grout. Unfortunately, the mud grouts were not deeply characterized and most of the times the evaluation was qualitative rather than quantitative, which does not allow drawing extended conclusions from these researches.

Roselund (1990, p.336-341) suggests a simple methodology, concerning compatibility and structural requirements, for injecting cracks of adobe constructions, as well as a procedure to do it. This study also stresses the shrinkage problems of mud grouts and the beneficial effect of the addition of stabilizers in this sense. It also shows concerns related with rheology of the tested grouts, by evaluating its fluidity by the consistency test and the penetrability by visual inspection. A more recent study, carried out by Vargas *et al.* (2008, p.1095-1099), also highlights the problem of the shrinkage in mud grouts, especially in the case of grouts with finer particles required for finer cracks. Another interesting conclusion stated in this study, is that the addition of stabilizers (such as cement, lime and gypsum) in quantities till 20% of the earth weight (no bigger percentages were tested) does not benefit the development of the bond between the grout and the adobe. However, the main conclusion of this work was that the injection of unstabilized mud grouts was effective in recovering or even increasing the original strength of damaged adobe wallets. Requiring, although, the injection to be well executed, evidencing the importance of the penetrability and fluidity of the mud grouts.

3.3 Design of mud grouts

A specific grout design methodology for earth constructions is not available yet. The methodology used for masonry can be adopted. Although, the grout design requirements have to be redefined specifically, since grouts incorporating different materials have to be developed in order to avoid compatibility and durability problems, and to avoid repeating the same errors committed in the past in the injection of historic masonry. As already stressed, incorporating earth in the composition of the grout is the most logical and suitable option for injecting earth constructions. However some problems and difficulties arise. Incorporating, in a mud grout, the same earth used for building the construction to be injected is the most economical solution and, probably, the material that would fit better the compatibility requirements. However, the quality that is demanded to the materials composing a grout does not allow it most of the times, due to the earth heterogeneity and properties divergent to the ones that are required to the grout. In this case, the selection of materials with controlled quality and superior homogeneity is preferable. The design of mud grouts is a complex task that depends on many variables, requiring a “non-linear system” to be solved, since all variables depend on each other. In Fig. 1 a design methodology proposal for mud grouts is represented, where each variable involved represents the properties that should be controlled in the definition of the grout. The properties arising are the bond, the rheological behaviour, the grout strength, the fresh state stability, the compatible microstructure and the chemical stability in the hardened state. Like for the design of a grout for injecting historical masonry, also the design of a mud grout must be concerned with the mechanical behaviour and durability of the construction.

Rheology:
The mud grouts must hold such rheological behaviour that allows them to completely fill cracks or voids laying in earth constructions. This is essential to assure the continuity of the repaired earthen walls and to re-establish the monolithic behaviour of the earthen structure. Thereby, all the factors influencing the rheology, such as the texture (particles size, distribution and shape), the interaction between particles (dispersion or flocculation), the quantity of solids in the grout, the mixing procedure and the action of superplasticizers or dispersants, must be carefully accounted for during the design of the mud grout. Moreover, the capacity of the dry earthen materials in absorbing quickly high amounts of water requires that the grout presents a great water retention capacity during its injection. This is essential in order to maintain its fluidity and penetrability during all the injection process.

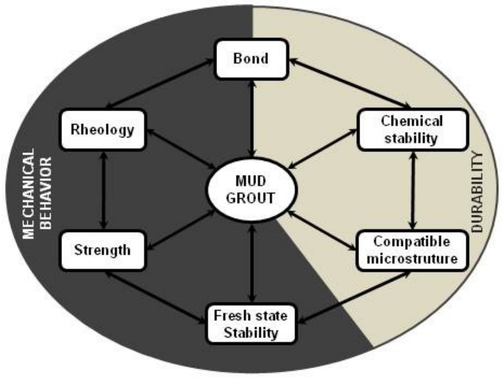

Fig.1 – Design methodology of mud grouts (credits: authors).

Strength:
The strength developed by the grout should be the one that the structural level of damage demands. However, employing grouts much stronger than the original earthen material should be avoided. Stiff grouts can cause problems of mechanical incompatibility, since the hardened grout hardly is able to follow the displacements occurring in the earth construction, resulting in damage to the intervention. Therefore, the addition of stabilizers has to be carefully considered, since it increases greatly the Young's modulus of the earthen materials. For example the Young's modulus of the unstabilized adobe of an old house can range between 80 N/mm^2 and 500 N/mm^2 (Silva, 2008, p 112), while a mud grout prepared with 40% of a binder (50% of hydraulic lime and 50% of cement) and 60% of earth (mixture of 30% of kaolin clay with 70% of sand) can present a Young's modulus ranging between 10340 N/mm^2 and 10590 N/mm^2 (On Yee, 2009, p. 64). However, not using a binder in a mud grout composition relies its hardening exclusively to the drying of the material. The drying of the mud grout is processed essentially through the water absorption of the original earthen material. This can be problematic if it is required to achieve a certain level of strength in short time span. The incorporation of hydraulic binders gives the mud grout a more independent behaviour.

Bond:
A good mud grout design requires that enough bond develops between the hardened grout and the original earthen material. This is essential for granting the continuity of the earthen structure, both for structural and durability reasons. The swelling/shrinkage nature of earth constitutes a major drawback. During the drying of a mud grout, its shrinkage can lead to cracking and consequently the required bond cannot be established. This is also a common problem found in reparation works using earthen materials (Keefe, 2005, p. 166). In order to overcome the shrinkage problem of mud grouts, several options can be suggested. The first consists in adopting selected clays with low shrinkage ratio in the composition of the grout, such as kaolinite clays. The

texture of the mud grout is another parameter which can be intervened, by decreasing clay content of the grout and by correcting the particles size distribution with addition of "unshrinkable" fine material (fly ash, silica fume, calcium carbonate powder, quartz powder and etc.). Another possibility consists in decreasing the water content. However, this has greater consequences on the rheology, which can only be counteracted by using dispersants that allow it. Using stabilizers is also an alternative to solve the shrinkage problem, but other problems can arise of this decision.

Chemical stability:
A mud grout also needs to present chemical stability over time. The salts content has to be limited in order to avoid efflorescence and crypto efflorescence problems. Moreover, the grout must present resistance to aggressive compounds present in the original materials of the construction. For example if a possible mud grout contains Portland cement, there is a possibility of formation of expansive products since the presence of sulphates is very common in earthen materials. In alternative, it can be used lime or hydraulic lime (if produced below the sintering temperature).

Stability during the fresh state:
During a mud grout fresh state, it must present stability. Therefore, it shall present limited bleeding, no segregation and adequate water retention. These are essential in order to assure that the mud grout maintains its fluidity and penetrability during the injection and remains homogenous after hardening. Therefore, using an earth with large particles in the composition of the mud grout for solving the shrinkage problem can constitute a major drawback since they easily tend to settle.

Compatible microstructure:
Obtaining a hardened mud grout microstructure compatible with the one of the original earthen materials is essential for fulfilling the durability requirement. The water vapour penetrating on the earthen materials has to be able to do it freely. If a grout with low porosity is injected, it can constitute a barrier, making the water vapour condensate. This is harmful for the intervention or for the construction, depending on the size of the intervention. The condensed water can leech the material around the grout disturbing the bond created, and therefore, damaging the intervention. In the cases where a big grout barrier is created, the condensed water can lead to the weakening of the earthen materials that at long-term can be responsible for an eventual collapse. Therefore, the incorporation of materials such as cement has to be carefully evaluated, since it reduces the porosity of the mud grout. The thermal properties of the hardened grout must also be closer to the ones of the original earth materials. This is even more important in monolithic earth constructions (for example rammed earth), where the grout has to be able to follow the thermal displacements of the earthen materials.

4. TESTING

4.1 Rheology

The experimental characterization of the mud grout is essential for achieving a suitable design. Therefore, a short description of suitable tests will be given in this section. As previously mentioned the rheological behaviour of a grout is of extreme importance to the success of the grouting intervention. Therefore, it is important to evaluate this behaviour experimentally even if not directly. There are three types of tests typically used to evaluate the rheological behaviour of grouts. The flow time test is performed by making a known quantity of liquid with a certain temperature flow by gravity through a Marsh's cone, and then by measuring the time required for emptying the cone. It is a very practical test, but it only allows getting an indirect measure of the fluidity, since the flow time depends on many other variables besides the rheological behaviour. Therefore, a direct relationship between the flow time and the rheological parameters that characterize the flow of a certain liquid cannot be established. The penetrability test consists in making a grout penetrate through a cylindrical column of sand with a specified permeability. The particles size and distribution of the sand are controlled in order to create a network of voids with specified dimensions. However, in order to simulate the absorption capacity of the dry earthen materials the sand can be substituted by brick dust. This is a test based on the visual inspection of the grout flow through the column that is injected at the bottom part with a certain pressure. Therefore the cylindrical container has to be made of transparent material. The flow curve determination is the only test that allows characterizing the rheological behaviour of a grout. This can be performed by resourcing to a rheometer that applies a programmed shear rate history (or another related quantity) to the grout and measures the response in terms of shear stress (or another related quantity). There are others rheometers that do the inverse. However, it is more usual resourcing to viscometers to characterize the rheological behaviour of grouts, which only allow applying and measuring a single flow condition at once. This implies repeating manually the test with different flow conditions in order to obtain the curve relating shear rate and shear stress. There are several kinds of viscometers with different limitations on the equipment or on the principles in which it is valid (minimum/maximum shear rate or shear stress) and with different accuracies. The grout rheological behaviour is normally associated to follow a non-Newtonian Bingham law in the flow domain in which the injection is executed. Therefore, the results obtained are fitted to this law in order to obtain the respective yield stress and plastic viscosity of the grout.

4.2 Strength

The strength of the mud grout is an important factor to be considered, regarding the structural demands of debilitated earth construction. Both the tensile and compressive strength of the grout should be evaluated. The three point bending test is the most common test to evaluate the tensile strength of grouts and also mortars. It consists in making a square cross section beam of grout, simply supported, break at the middle span section due to a load applied in this same section. The ultimate bending allows calculating the maximum tensile stress upon collapse, by considering a linear elastic behaviour. This test normally overestimates this property, but is less expensive and more practical than the direct tensile test. The compression test consists in making a grout specimen, with a specified cross section and height, collapse by compressing it. If the displacements of the specimen are measured during the test, important mechanical parameters, such as Young's modulus and Poisson coefficient, can be computed, besides the compressive strength.

4.3 Bond

The bond created between the grout and the original earthen materials is of great importance for granting the continuity and durability of the construction. The shrinkage of the grout directly affects the bond, and therefore is another property that should be evaluated. To evaluate the bond created, special specimens consisting in "sandwiches" made by injecting a grout between two pieces of the earthen material must be first prepared. The tensile bound can then be tested by directly pulling the two pieces or by submitting the specimen to a 3- or 4-point bending test. The shear bond also can be carried out with the same kind of specimens, by submitting them to a shear-box test. The linear shrinkage test consists in making a specimen of hardened grout with a specified geometry and dimensions. Then the distance between two points of the grout is measured over time till it reaches a stable value. This allows computing the linear shrinkage of the grout.

4.4 Chemical stability

In order to grant a durable repairing solution, the selected materials for composing the grout should present chemical resistance to aggressive compounds present in the earthen materials. The products resulting from the hardening of the grout must also present a stable chemistry that avoids their transformation in product that may be responsible for durability problems. Therefore, both the grout and the earthen material have to be chemically tested. The chemical analyses performed on the earthen materials and on the materials composing the mud grout, are useful for identifying compounds likely to be involved in harmful reactions. This is helpful to limit the quantity or prevent the addition of a harmful material to the mud grout. The x-ray diffraction technique (XRD) is useful for identifying the clay fraction mineralogy both in the mud grout and earthen material. This allows identifying expansible clay minerals that might be responsible for inappropriate grout shrinkage or swelling problems due to the contact of the earthen materials with water. The thermogravimetric analysis technique (TGA) and the complementary first derivate of thermogravimetry technique (DTG) are useful techniques for monitoring the transformation of hydration and carbonation products in mud grouts where binders were used. By doing this, it allows verifying the grout stability over time.

4.5 Stability during the fresh state

A grout, when in its fresh state, must present stability, i.e., the solid particles must be suspended in the liquid phase during a period of time that does not compromise the homogeneity of the hardened grout or the injection process (blocking of the voids network due to settlement of the larger particles). Therefore, it is necessary to determine experimentally how stable the proposed grout is. The bleeding test consists in filling a graduated cylinder with the fresh grout and measuring over time the height of the water layer appearing on top, resulting from the bleeding and segregation of the grout. This is a simple test, however it is insufficient to evaluate the stability of a mud grout, because it only evaluates what happens at the surface and the segregation is only detected when the water layer becomes visible. The density stability test constitutes an alternative with the advantage of not requiring visual inspection to evaluate the grout stability. This test is performed by hanging in the fresh grout an object with a specific volume, and then by measuring the buoyancy force over time. This force is proportional to the density of the grout according to Archimedes's law. Due to the settlement over time of the larger particles, the density of the grout decreases, being reflected in decrease of the measured buoyancy force.

4.6 Microstructure

As stated before, having mud grouts with a compatible structure is fundamental for achieving a durable grouting solution. Therefore, the porosity of the grout should be experimentally evaluated. However, evaluating experimentally the porosity of earthen materials is normally a difficult task, since the traditional methods result in the disintegration of the specimen before ending the test. Methods that involve submerging the specimen in water fail in determining the open porosity due to the lack of resistance of earthen materials to water. The mercury intrusion is also an ineffective technique since the pore structure fails due to the pressure. However by knowing the density of the material, by using a pycnometer, it is possible estimate the total porosity of a mud grout.

5. CONCLUSION

Grout injection of mud grouts has many advantages as a repair technique for earth constructions, when compared with traditional techniques for structural repair of cracks. In particular, a previous study showed the effectiveness of the grout injection in recovering the original strength of the earth constructions. Nevertheless, the knowledge about mud grouts was demonstrated still to be very limited, particularly in the domain of their rheology. Additionally, the irreversible nature and complexity of the grouting technique demand the development of a grout design methodology that grants the long-term durability of this kind of interventions. Therefore, an initial methodology for mud grouts design is proposed in this paper, based on the grout design methodology for historical masonry. The continuous development of this methodology can only be achieved if the knowledge about mud grouts is also developed through experiments. This is within the scope of the ongoing research being carried out by the authors.

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